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IS THE WHITE RIVER TERTIARY AN ÆOLIAN FORMATION?

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When the Cenozoic of the Great Plains of western North America was explored in the fifties and sixties, the theory was formulated that it was deposited as sediment in a succession of vast fresh-water lakes. This view was generally held until the recent explorations, especially under auspices of the United States Geological Survey, which have caused it to be considerably modified. The Loup Fork has been shown to be largely a flood-plain deposit, the Pleistocene chiefly æolian; and Mr. Darton has lately traced an extensive system of river deposits overlying the White River clays. The main body of the White River formation, consisting of fine-grained calcareous "clay," or chalk, with intercalated beds and lenses of sandstone, usually of limited extent and in subordinate amount, has, I believe, been universally considered lacustrine.

There are some very serious difficulties, stratigraphic and paleontologic, in the way of this theory, and observations in Kansas, Nebraska, and Colorado, during the last two summers, suggested to the writer another view, which appears to do away with these difficulties.

OBJECTIONS TO THE LACUSTRINE HYPOTHESIS.

I. *Stratigraphic.*—(*a*) We must assume the former existence of a vast lake covering a large part of Nebraska, Colorado, Wyoming, South Dakota, and perhaps extending even farther northward, with an area dwarfing into insignificance any existing lake. We must assume an eastern and southern barrier high enough and extensive enough to hold in these waters during the entire Oligocene period, which yet entirely escaped erosion, and subsequently disappeared, leaving no trace, direct or indirect, of its former existence.

(*b*) So large a lake should surely have left strongly marked wave-cut terraces on its shores and islands. I have never seen or heard of any such (as distinguished from wind-cut terraces), although the short-lived glacial lakes gave rise to abundant evidence of this sort.

(*c*) There is a general absence of minute stratification in the clays. They contain heavy beds or layers of different color or hardness, but no fine stratification or horizontal cleavage. The Niobrara Cretaceous, composed of equally fine material, not very different in composition, shows a marked contrast in this respect, fine stratification being universal.

II. *Faunal.* — These difficulties are yet more serious.

(*a*) There are no plants — tree trunks, stems, or leaves — in the clays, although these deposits are well fitted to preserve them. The plant remains that I have seen are limited to the coarser (fluviatile) beds above. Plant remains have been described from the "Bad Lands of Dakota,"[1] but I do not know their exact occurrence.

(*b*) There are no aquatic invertebrates.

(*c*) There are no fish.

(*d*) There are no aquatic reptiles; but land tortoises[2] are the most abundant fossils found, and lizards and snakes occur in considerable variety. The only exceptions to this statement, as far as I know, are a crocodile skull and two specimens of Trionyx, found in South Dakota; but whether in the clays or not, I am uninformed.[3]

(*e*) Mammals occur in great numbers and variety, scattered all through the clays. Of over fifty genera only three are probably aquatic; most of them are land mammals, some are of uncertain habitat. The three aquatic forms are a rhinoceros, Metamynodon, confined to a single layer of *sandstone* in the Oreodon beds, and an oreodont, Leptauchenia, and a beaver,

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[1] Lesquereux. *Cretaceous and Tertiary Flora.*

[2] Family Chersidæ, genera Testudo, Stylemys (? = Testudo), — Zittel, *Handbuch von Paläontologie.*

[3] One of the specimens of Trionyx is certainly from the sandstones.

Steneofiber, confined to the probably fluviatile beds at the top of the White River.

The fauna of the clays is, then, exclusively a land fauna. The lacustrine theory requires us to suppose that the animals were swept down by rivers into the lake. Modern rivers do sometimes bring down carcasses of land animals in their floods, along with an overwhelmingly greater amount of tree trunks, leaves, etc., and mingle these with their delta deposits, forming estuarine or delta beds, a well-marked facies of sediments. But the White River clays are not delta deposits; they must, if lacustrine, have been deposited far out in the open lake. How did the land animals get out into this open lake? The current could not take them out, for it was insufficient even to arrange the fine particles of sediment. They might conceivably have floated out. But why in such numbers and so uniformly distributed? How did separate limbs, gnawed, bitten, or weathered bones get there? How did the tortoises get out into the lake? Why were no tree trunks or plant remains floated out, if the animal carcasses could float out? Why are there no fish or invertebrate remains? Contrast this fauna with the Cretaceous, where marine reptiles, fish, and invertebrates are exceedingly numerous, amphibious and land animals extremely rare, and plant remains by no means common. Contrast it with known lacustrine deposits, as some of the small Pleistocene lakes of the east, where fresh-water invertebrates are very abundant, fresh-water fish common, and land plants or water plants, or both, often make up a large part of the deposits, while land animals are rare, except in peat bogs.

If, then, the White River clays are lacustrine, they must have been deposited in an absolutely lifeless sea, surrounded by a well-watered region devoid of vegetation, yet sustaining an animal population of incredible density. And even this combination of improbabilities cannot account for some facts, and does not satisfactorily account for others.

MODERN DEPOSITS OF THE PLAINS.

There are two kinds of deposition now going on in this region:

I. *River and Flood Plain Sediments.* — Sands and clays are deposited in the valleys whenever continental deformation causes a decrease in the fall of the river bed. Mr. Gilbert's clear exposition of this mode of sedimentation, as exemplified in the Arkansas valley, makes further comment superfluous.[1]

II. *Prairie Loess.* — Wind erosion (deflation), very active in this arid region, carries off from all exposed rock or soil a large amount of material, most of which is deposited on the sodded, or partially sodded, prairie surface. The deposit is heavier in hollows, where temporary "lagoons" or denser grass occur, and tends to produce an extremely level and uniform surface. This deposition through the Pleistocene has produced a fine unstratified, extremely uniform covering of loam (loess or marl) over the greater part of the plains; I have seen it in places two hundred feet thick. It was formerly supposed to be a lacustrine sediment, and that the rivers subsequently cut their channels in the floor of the dried-up lake. It is now, I believe, generally considered æolian, and a significant corollary of the mode of deposition, outlined above, is that it was built up at the sides of the river valleys, deposition in the valleys being checked by erosion; the valleys, therefore, are older than the plains.

Practically the only fossils found in the loess are the bones of land animals. No plant remains occur; the prolonged exposure to water and air permits the nearly complete oxidation of vegetable matter. Near the surface are peaty layers and land shells, but the conditions of burial do not favor their fossilization. Dark lines mark the position of lagoons on the former prairie surface, and slight changes in the quality or fineness of the deposit produce a bedded appearance, uniform over large areas. The extent and uniformity of this Prairie Loess are especially notable. It is the prevalent surface deposit over half a dozen western states in the greater part of the plains region.

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[1] *U.S. Geol. Survey*, *XVIIth Ann. Rep.*, Pt. ii, p. 575.

The occurrence of mammal bones on the surface may be taken as indicating the way they occur within the loess. Skeletons are more or less complete according to the extent of disturbance by carrion feeders. Skulls, limbs, or individual bones are commonly found separated — carried off by other animals. Limbs are very apt to be bitten off across the upper limb bone, leaving the head of the humerus or femur in its socket. Bones are often more or less gnawed or bitten, sometimes weathered, but never water-worn. In and around "salt licks," or lagoons, a mingled heap of bones of many animals is often found, individuals usually hopelessly mixed.

The upper part of the Prairie Loess contains bones of Bison and other modern prairie inhabitants in various early stages of fossilization. The lower part contains Equus bones.

THE ÆOLIAN HYPOTHESIS.

I believe that the White River clays, in Colorado at least, are chiefly æolian deposits, similar in origin to the Prairie Loess. Most of the sandstones are probably fluviatile, especially those occurring in lenticular masses. The sandstones with the *stratified* clays parallel the modern fluviatile deposits of the valleys. Some sandstones may be æolian.

1. The fauna is what we should expect to find in an open, grassy region. The animals are all land forms, and the most abundant genera, Oreodon, Mesohippus, and Hyracodon, have distinctively *cropping* teeth. The abundant and varied fauna has been supposed to indicate a warm, moist climate; it is paralleled, however, by that of the dry region of South Africa, and the modern fauna of the plains is by no means small. The occurrence of land tortoises cannot be explained by the lake theory, and its explanation of the other land fauna appears an exceedingly improbable one, involving several practical impossibilities, as noted above.

2. The occurrence of specimens is precisely, in every detail, the same as above stated in the modern prairie deposits, and their abundance in Colorado is about the same. Gnawed bones,

bitten off limbs, mixed accumulations in fine uniform sediments, are inexplicable on the lake hypothesis.

3. The character of the clays is exactly what the loess would probably assume on consolidation, and does not agree with the Niobrara chalk, a deposit similar in origin to that proposed by the lacustrine theory for the White River clays, except that the water was salt instead of fresh.

4. The great extent and uniformity of the White River and the details of its distribution appear to the writer to agree with that of the loess, but to be difficult to explain on the theory of lake deposition.

This view of the origin of the White River beds involves a great change in our notions of the climate and conditions of the west in the later Tertiary. If it be correct, these must have been much like those now prevailing in the same region; and our ideas as to the probable appearance and habits of these extinct animals can be made much more definite and certain.

This theory has probably little or no application to the Eocene beds west of the Rockies. These do not contain the fine unstratified chalks; they are in well-defined basins enclosed by mountain ranges and drained by great canyons; land tortoises are as rare in them as water tortoises in the White River; alligators, etc., occur frequently, and the characteristic plains types of mammals of the White River are small, scarce, or undeveloped. Furthermore, before the Sierras and Coast Range were elevated, the rain now falling on the Pacific Coast must have fallen where the Great Basin now is; while we have no *known* adequate cause for so great a change in the climate of the plains between the Oligocene and the present time. The Eocene deposits are probably a mixture of lake and fluviatile sediment—what proportion of each would not be easy to determine.